

Abstract**RADIATION RESPONSE ISSUES
FOR INFRARED DETECTORS**

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One important issue facing space systems is survivability and operability in radiation environments. All space systems will be subject to the natural space environment, and most DoD and SDI systems must also be concerned with the much higher radiation environments produced by nuclear weapons. As a result, survivability and operability are necessary requirements that must be met by any space system.

Historically, infrared detectors (which are the key component in sensor subsystems) have been very vulnerable to nuclear radiation exposure. Most semiconductor components are subject to a variety of radiation-induced degradation mechanisms, and infrared detectors are no exception. In addition, high-quality infrared detectors are extremely sensitive detectors of optical photons, but this also makes them very sensitive to gamma photons, electrons, and protons.

Although some infrared detector technologies are less vulnerable to nuclear radiation than others, and hardening approaches have been developed for some of the technologies, there is no realistic expectation that the vulnerability problem will be completely eliminated for any infrared detector technology. Therefore, it is necessary to understand the vulnerability issues presented by nuclear radiation exposure, so that ones that impact sensor performance can be addressed.

In this paper, we will describe the most important radiation response issues for infrared detectors. In general, the two key degradation mechanisms in infrared detectors are the noise produced by exposure to a flux of ionizing particles (e.g.; trapped electrons and protons, debris gammas and electrons, radioactive decay of neutron-activated materials) and permanent damage produced by exposure to total dose. Total-dose-induced damage is most often the result of charge trapping in insulators or at interfaces. Exposure to short pulses of ionization (e.g.; prompt x-rays or gammas, delayed gammas) will cause detector upset. However, this upset is not important to a sensor unless the recovery time is too long. A few detector technologies are vulnerable to neutron-induced displacement damage, but fortunately most are not.

We will discuss the radiation responses of various infrared detector technologies, emphasizing where possible the responses of the newer technologies that are the subject of the Workshop. Because of the newness of most of these technologies, much of this will be analytical projections of the radiation response. In some cases, we will not even be able to accomplish the analytical predictions because of a lack of sufficient information about the use of the technology as an infrared detector. We will compare the responses of the newer technologies with those of the mainstream technologies of PV HgCdTe and IBC Si:As. One important reason for this comparison is to note where some of the newer technologies have the potential to provide significantly improved radiation hardness compared with that of the mainstream technologies, and thus to provide greater motivation for the pursuit of these technologies.

RADIATION RESPONSE ISSUES FOR INFRARED DETECTORS

**PRESENTED AT:
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JET PROPULSION LABORATORY**

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RADIATION HARDNESS IS A BASIC REQUIREMENT, NOT AN ADD-ON, FOR SPACE SYSTEMS

- **NATURAL SPACE RADIATION ENVIRONMENT EXISTS AT ALL TIMES**
 - **NATURAL RADIATION ENVIRONMENT AROUND EARTH MAY BE RELATIVELY BENIGN, BUT LONG-DURATION MISSIONS CAN ACCUMULATE HIGH DOSE**
 - **NASA MISSIONS TO OUTER PLANETS CAN ENCOUNTER RADIATION ENVIRONMENTS MUCH HIGHER THAN EARTH'S**
- **SDI AND DoD SYSTEMS MUST SURVIVE THE NUCLEAR-ENHANCED ENVIRONMENTS**
- **IR DETECTORS WILL HAVE TO BE HARD, OR THEY WILL NOT BE USED FOR SPACE APPLICATIONS, PARTICULARLY IN THE SDS**
 - **ONE SHOULD NO LONGER ASSUME THAT ONE CAN DEVELOP A COMPONENT OR SUBSYSTEM, AND THEN THINK ABOUT HARDENING**
- **HARDENING MUST BE CONSIDERED FROM THE BEGINNING**

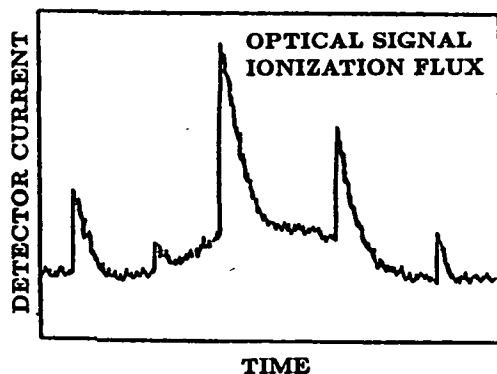
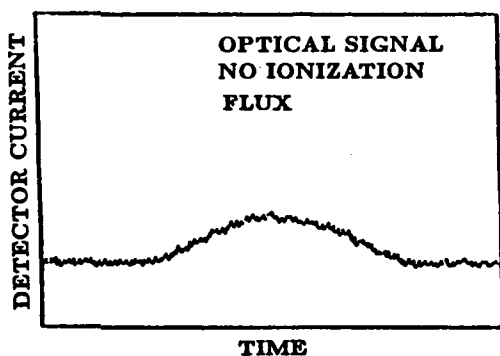


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THERE ARE SEVERAL RADIATION HARDNESS ISSUES THAT ARE IMPORTANT

- **OPERABILITY DURING EXPOSURE TO A FLUX OF IONIZING PARTICLES**
 - TRAPPED ELECTRONS OR PROTONS, DEBRIS GAMMAS OR ELECTRONS, DECAY OF ACTIVATED MATERIALS, ETC.
- **SURVIVABILITY FOLLOWING TOTAL-DOSE EXPOSURE**
 - TRAPPED ELECTRONS OR PROTONS, PROMPT X-RAYS OR GAMMAS, DELAYED OR SECONDARY GAMMAS, ETC.
- **UPSET/RECOVERY WHEN EXPOSED TO PROMPT PULSE**
- **SURVIVABILITY FOLLOWING NEUTRON EXPOSURE**
- **ISSUES THAT ARE MORE SYSTEM-RELATED WILL NOT BE DISCUSSED**
 - OPERABILITY IN THE PRESENCE OF NUCLEAR-INDUCED OPTICAL CLUTTER
 - RECOOLING FOLLOWING NUCLEAR-INDUCED HEATING
 - SGEMP/IEMP

OPERABILITY IN A GAMMA-FLUX ENVIRONMENT REMAINS A KEY ISSUE FOR INFRARED SENSORS

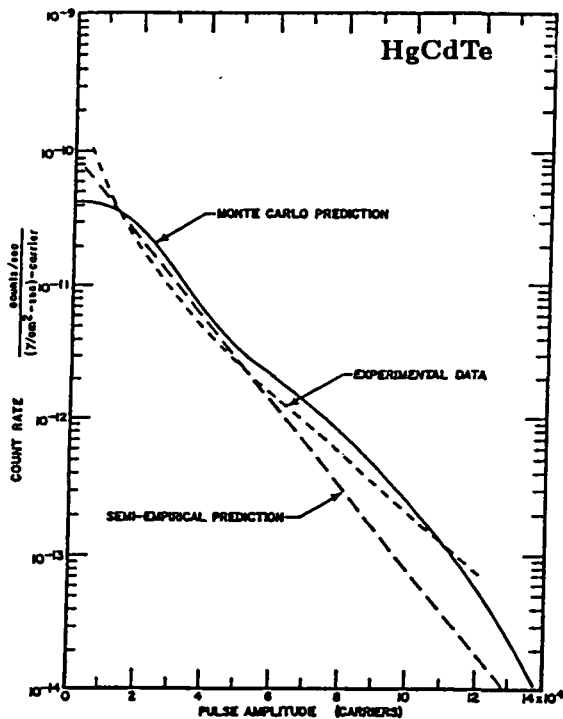


- **DETECTORS ARE SO SENSITIVE THAT CHARGE DEPOSITED BY A SINGLE IONIZING PARTICLE CAN COMPLETELY MASK THE OPTICAL SIGNAL**
- **DETECTORS ARE RELATIVELY LARGE, SO EVENT RATES ARE HIGH**
 - ALL PIXELS CAN BE CONTAMINATED AT RELATIVELY LOW FLUX



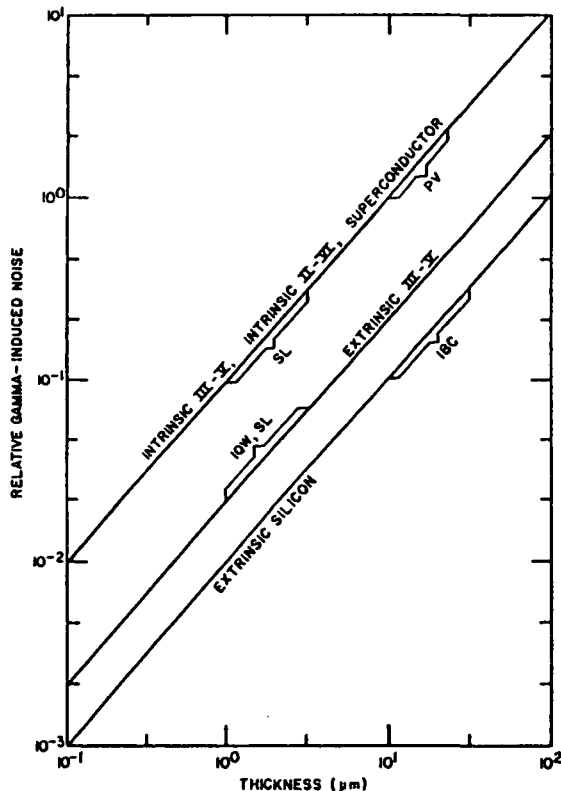
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IONIZATION-INDUCED PULSES IN LWIR DETECTORS ARE PARTICULARLY LARGE



- DETECTORS ARE VERY SENSITIVE ANALOG DEVICES
- PULSES PRODUCED BY IONIZING PARTICLES CAN COMPLETELY MASK OPTICAL SIGNALS
 - $\langle n \rangle \approx (E/L) \cdot \langle x \rangle / \epsilon_p$
 - $R \approx \mu L \langle A_p \rangle \dot{\gamma}$
 - $i_n \approx 2e \langle n \rangle (R(\Delta f))^{1/2}$
- EFFECT IS TRANSIENT, AND OCCURS ONLY WHEN DETECTORS ARE EXPOSED TO FLUX

SELECTION OF DETECTOR TECHNOLOGY CAN IMPACT OPERABILITY IN IONIZING-FLUX ENVIRONMENT

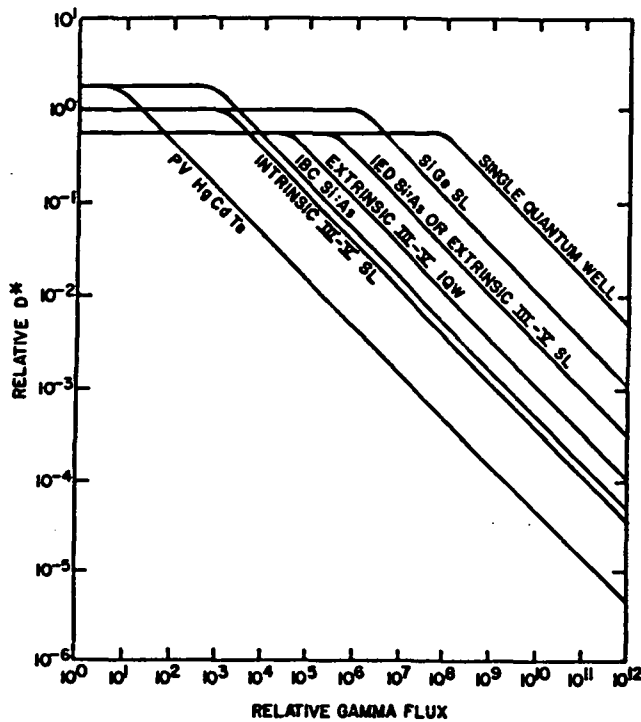


- HIGHER α FOR THINNER DETECTORS
- EXTRINSIC DETECTORS FOR HIGHER ϵ_p
 - ADVANCED HARDENING CONCEPTS ARE MORE LIKELY FOR EXTRINSIC DETECTORS



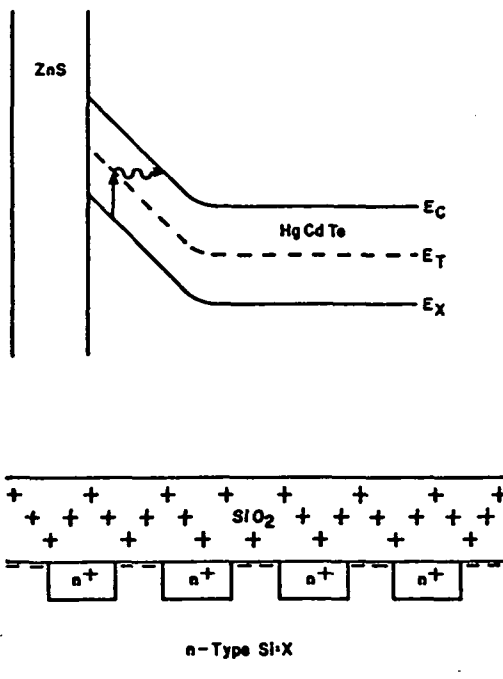
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MANY OF THESE INNOVATIVE DETECTOR CONCEPTS GIVE PROMISE OF IMPROVED HARDNESS TO IONIZING PARTICLE FLUX



- PRIMARY ADVANCE IS DETECTOR THINNESS
- MOST OF CURVES BASED ON ANALYTICAL PREDICTIONS
- GaAs/AlGaAs QUANTUM WELL CURVE BASED ON EXPERIMENTAL DATA

SURVIVABILITY FOLLOWING TOTAL-DOSE EXPOSURE IS ALSO AN IMPORTANT ISSUE

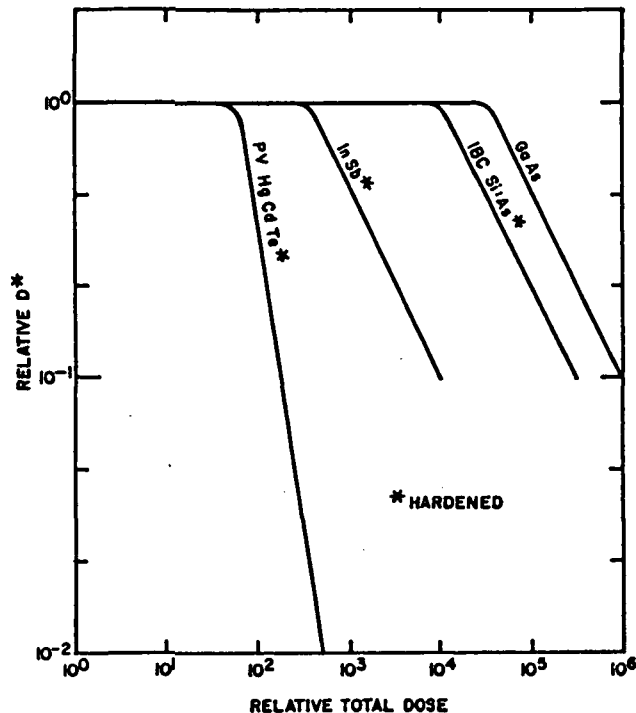


- DAMAGE MECHANISM IS TRAPPING OF RADIATION-INDUCED CHARGE IN INSULATORS OR AT INTERFACES
- DAMAGE IS PERMANENT
- NARROW-BANDGAP SEMI-CONDUCTORS ARE PARTICULARLY VULNERABLE TO TUNNELING EFFECTS
- HIGH IMPEDANCE DEVICES ARE PARTICULARLY VULNERABLE TO SURFACE LEAKAGE



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DETERMINING TOTAL-DOSE HARDNESS OF ANY TECHNOLOGY USUALLY ACCOMPLISHED ONLY BY EXPERIMENT



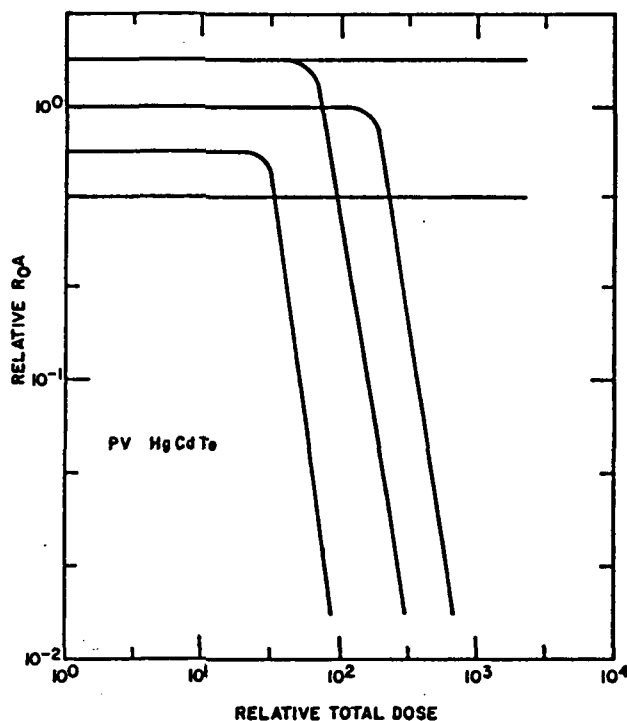
- MOST SEMICONDUCTOR TECHNOLOGIES WITH INSULATORS ARE VULNERABLE TO TOTAL DOSE

- INCLUDES Si, Ge, AND MOST III-Vs
- PINNED SURFACE POTENTIAL MAKES GaAs AN EXCEPTION

- HARDENING APPROACHES CAN BE DEVELOPED

- TUNNELING MAKES PROBLEM MORE DIFFICULT FOR NARROW BANDGAP MATERIALS

HARDENING OF HgCdTe AGAINST TOTAL-DOSE EXPOSURE HAS PROVEN TO BE PARTICULARLY DIFFICULT



- DAMAGE MECHANISM NOT WELL UNDERSTOOD

- ANY OF SEVERAL DIFFERENT MECHANISMS CAN DOMINATE OBSERVED DAMAGE

- STANDARD HARDENING APPROACHES HAVE NOT BEEN EFFECTIVE

- HARDNESS HAS NOT BEEN REPEATABLE

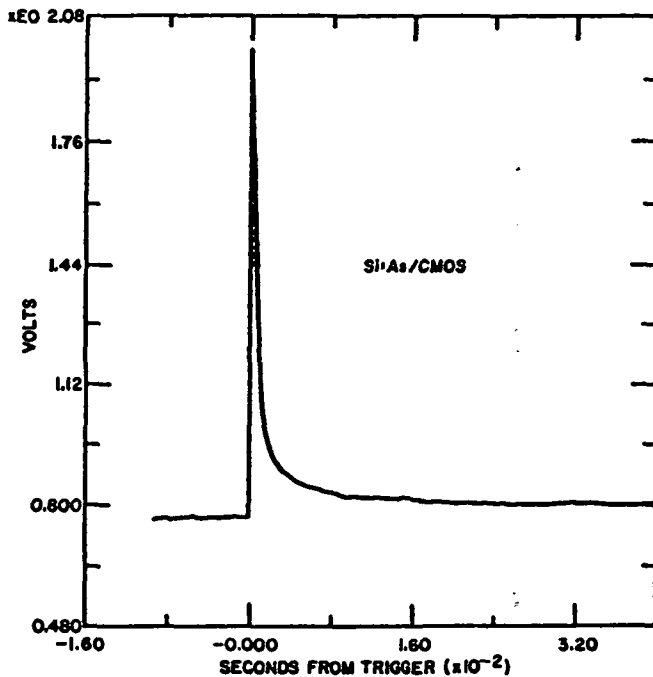
- VARIATION IN HARDNESS OFTEN OBSERVED IN SAME ARRAY

- ONE QUESTION IS WHETHER SIMILAR PROBLEMS WILL BE ENCOUNTERED FOR ANY NARROW-BANDGAP SEMICONDUCTOR



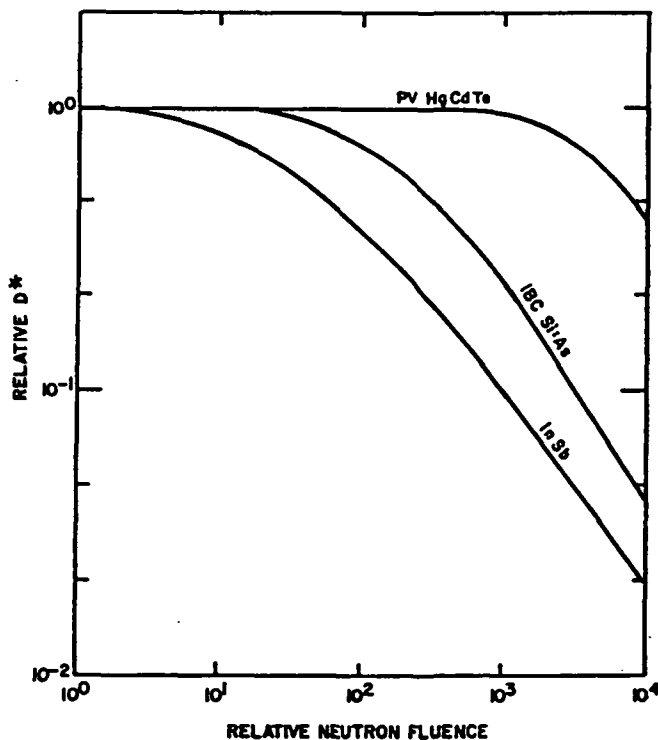
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RECOVERY TIME IS KEY ISSUE FOR PROMPT-PULSE EXPOSURE



- UPSET THRESHOLD IS SO LOW THAT UPSET IS SURE TO OCCUR
 - ISSUE IS RELATIVELY INDEPENDENT OF DETECTOR TECHNOLOGY
 - SYSTEMS MUST BE DESIGNED TO IGNORE THIS UPSET
- RECOVERY, ESPECIALLY IN MULTI-BURST ENVIRONMENT, IS KEY
- READOUT OFTEN GOVERNS RECOVERY OF FPA, BUT DETECTOR RECOVERY MUST BE CONSIDERED
 - RECOVERY AT CRYOGENIC TEMPERATURE CAN BE LONG

MOST DETECTOR TECHNOLOGIES ARE RELATIVELY HARD TO NEUTRON EXPOSURE



- PERMANENT DEGRADATION PRODUCED BY NEUTRON-INDUCED DISPLACEMENTS
- Si:X AND InSb ARE EXCEPTIONS
- ANALYTICALLY PREDICTING THE NEUTRON RESPONSE OF A NEW TECHNOLOGY IS DIFFICULT



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SUMMARY

- **RADIATION HARDNESS IS ONE OF THE BASIC REQUIREMENTS FOR LWIR DETECTOR TECHNOLOGIES DEVELOPED FOR SPACE APPLICATIONS**
- **IONIZING-PARTICLE-FLUX AND TOTAL-DOSE HARDNESS ARE THE MOST IMPORTANT OPERABILITY/SURVIVABILITY ISSUES**
 - **THESE ISSUES EXIST FOR BOTH NATURAL-SPACE AND NUCLEAR-WEAPON-ENHANCED ENVIRONMENTS**
- **RECOVERY FOLLOWING PROMPT-PULSE EXPOSURE AND SURVIVABILITY FOLLOWING NEUTRON EXPOSURE ARE SECONDARY ISSUES FOR MOST DETECTOR TECHNOLOGIES**
 - **RECOVERY TIME IN MULTI-BURST ENVIRONMENT CAN BE IMPORTANT**
 - **THESE ISSUES ONLY EXIST FOR NUCLEAR-WEAPON-ENHANCED ENVIRONMENTS**
- **MANY OF THE PROPOSED INNOVATIVE TECHNOLOGIES HAVE POTENTIAL HARDNESS ADVANTAGES OVER THE EXISTING MAINSTREAM TECHNOLOGIES OF HgCdTe AND IBC Si:As**



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